

Hot Operating Temperature Lithium combustion IN situ Energy and Power System (HOTLINE Power System)

Completed Technology Project (2017 - 2020)



Project Introduction

The challenge of energy storage and power generation for a planetary lander is significantly magnified when considering a Venus mission. We propose to leverage decades of development of a TRL 9 U.S. Navy undersea power system to enable in situ exploration for hundreds of hours rather than hundreds of minutes, which is typical of past Venus landers as well as currently considered concepts, such as the 2013 Decadal Survey Venus concept Mission, VITAL. By significantly increasing operational time on the surface of Venus, missions are far more likely to return the expected science, will offer mission operators the opportunity to interact with the environment, chose specific science targets near the lander, and deal with anomalies that would jeopardize a two-hour-long mission. We propose to advance the TRL 9 Stored Chemical Energy Power Systems (SCEPS), which burn lithium. SCEPS systems have long provided both electrical and propulsive power for underwater systems and are well suited to the rigors of planetary exploration. Conventional SCEPS engines make power by burning molten lithium with sulfur hexafluoride vapor, using the heat to drive a Rankine power cycle. The inherently high energy density of SCEPS is magnified for Venus applications, since the carbon dioxide atmosphere can be used as the oxidizer, significantly increasing the system-specific energy density through in situ resource utilization. Our focus for HOTTECH is the demonstration of a high-temperature Rankine cycle to make power on Venus. Through a 2011 Phase I grant from the NASA STMD we analyzed a complete Venus mission concept and begun characterization of lithium/CO₂ combustion. Through our 2015 NIAC Phase II grant, we have demonstrated SCEPS reactor operation burning lithium with a gas mixture representative of the Venus atmosphere (97% CO₂, 3% N₂). We have modeled the fundamental physics of lithium and CO₂ combustion, allowing us to estimate performance of this innovation on conventional SCEPS systems and make comparisons to the results of ongoing tests. We have analyzed a Rankine cycle that uses elemental iodine as the working fluid, which will reject its heat to the Venus atmosphere and condense into the liquid necessary for the pump-side of a Rankine cycle to work. We will build and test a physical system that demonstrates this capability. This system can also provide refrigeration for other components. We believe that active cooling and relatively long duration operations will enable NASA to execute missions to the surface that address the Agency's goals for Venus exploration. To ensure that our conceptual system and this demonstration of a high-temperature Rankine cycle would truly serve an in situ Venus mission, our team includes not only power-system engineering expertise but also mission development and Venus science expertise. We believe that using SCEPS on the surface of Venus can enable NASA's plans to explore our sister planet. If selected, the HOTLINE project will, over the course of a three-year period: - Align SCEPS capability and our target power and energy levels to the needs of published NASA missions. - Perform analysis and design of an end-to-end power system that meets a parameterized mission's requirements. - Design and build a test article that heats the selected working fluid to operational temperatures,



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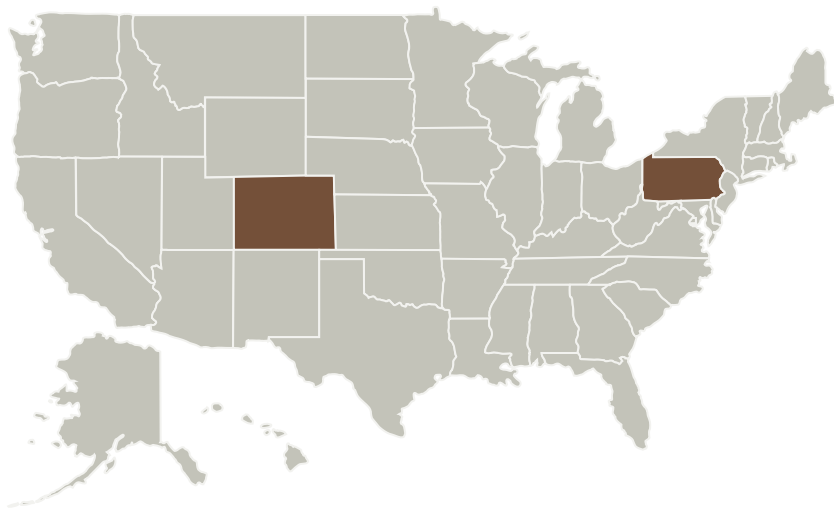
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drives a turbine to steady-state operation, measures work output by the turbine, and then condenses the working fluid by rejecting heat to a simulated Venus environment. - Run multiple tests at different operating conditions to characterize the thermodynamic state parameters at critical points in the Rankine cycle. - Publish both the conceptual end-to-end system analysis and the results of the testing.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Pennsylvania State University-Main Campus(Penn State)	Lead Organization	Academia	University Park, Pennsylvania

Primary U.S. Work Locations	
Colorado	Pennsylvania

Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

Pennsylvania State University-Main Campus (Penn State)

Responsible Program:

Hot Operating Temperature Technology

Project Management

Program Director:

Carolyn R Mercer

Program Manager:

Quang-viet Nguyen

Principal Investigator:

Michael V Paul

Co-Investigators:Alexander S Rattner
Sonny Harman
Larry W Esposito
Christopher J Greer
Travis L Swires

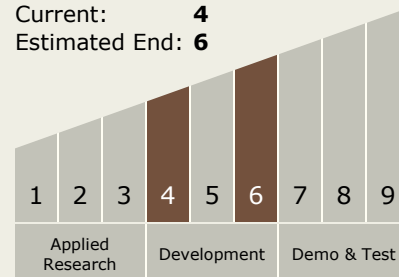
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Technology Maturity (TRL)

Start: **4**
Current: **4**
Estimated End: **6**



Technology Areas

Primary:

- TX08 Sensors and Instruments
 - └ TX08.3 In-Situ Instruments and Sensors
 - └ TX08.3.4 Environment Sensors

Target Destination

Others Inside the Solar System